EEC4122: Satellite Communication Systems

The Geostationary Orbit

Mahmoud Selim

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Tanta University

Introduction

- A satellite in a geostationary orbit appears to be stationary with respect to the earth
- Three conditions are required for an orbit to be geostationary:
  - satellite must travel eastward at the same rotational speed as the earth
  - The orbit must be circular
  - The inclination of the orbit must be zero (in Equatorial plane)[GSO orbit]
- The semi-major axis of geo orbit a_{GSO} (equal to radius in circular) is

$a_{GSO} = (\frac{\mu P^2}{4\pi^2})^{1/3}$and P is 23h, 56m and 4s (time taken by earth for complete revolution about N-S axis → sidereal day)

- hence, $a_{GSO} = 42164\ km$ and the geostationary height is

$$h_{GSO} = a_{GSO} - a_E = 42164 - 6378 = 35786\ km$$

Introduction

- a precise geostationary orbit cannot be attained because:
  - **gravitational fields of the sun and the moon**: produce a shift of about 0.85°/year in inclination
  - **earth’s equatorial ellipticity**: causes the satellite to drift eastward along the orbit causing longitude drift
  - In practice, station keeping maneuvers have to be performed periodically to correct for these shifts
- There is only **one** geostationary orbit (scarce resource)!

Antenna Look Angles

- are the azimuth and elevation angles required at the ground station antenna so that it points directly at the satellite
- Since satellites are geostationary to earth, no tracking mechanism is required and antennas can be fixed in position
- Three pieces of information are required to determine look angles:
  - Earth station latitude (λ_E)
  - Earth station longitude (ϕ_E)
  - Satellite longitude (longitude of the sub-satellite point) (ϕ_{SS})
- latitudes north will be taken as **positive angles**, and latitudes south, as **negative angles**
- Longitudes east of the Greenwich meridian will be taken as positive angles, and longitudes west, as negative angles
- variation in Earth radius is negligible and the average radius of the earth will be used (R = 6371 km)

Antenna Look Angles

- Six angles are defining the **spherical triangle**: a, b, c, A, B and C
- Considering first the spherical triangle, the sides are all arcs of great circles, and these sides are defined by the angles **a, b, and c** subtended by them at the center of the earth
- The three angles ***A, B,* and *C*** are the angles between the planes

Antenna Look Angles

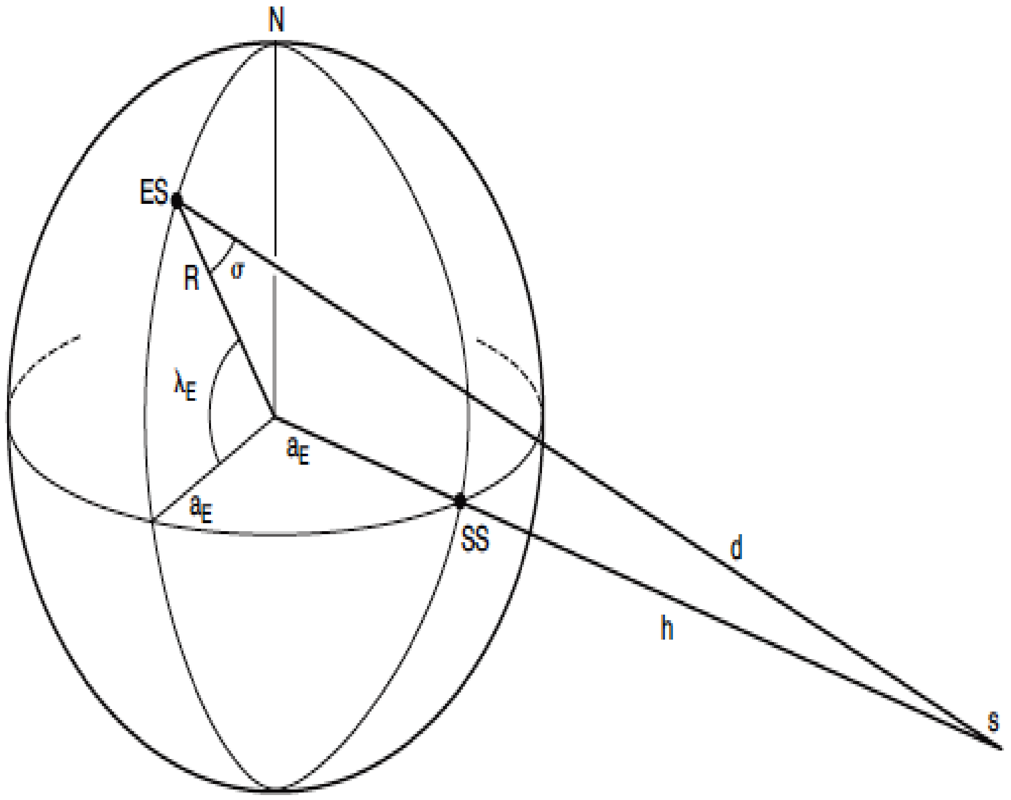


Figure 3.1 The geometry used in determining the look angles for a geostationary satellite.

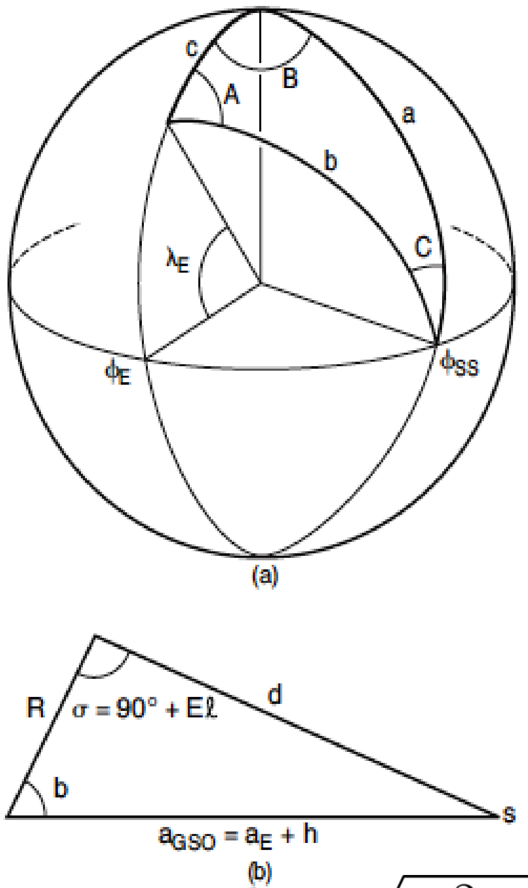


Figure 3.2 (*a*) The spherical geometry related to Fig. 3.1. (*b*) The plane triangle obtained from Fig. 3.1.

$$a = 90^\circ$$
$$c = 90^\circ - \lambda_E$$
$$B = \phi_E - \phi_{SS}$$

Napiers rules:

$$b = arccos(cosBcos\lambda_E)$$
$$A = arcsin(\frac{sin|B|}{sinb})$$

$$d = \sqrt{R^2 + a_{GSO}^2 - 2Ra_{GSO}cosb}$$
$$El = arccos(\frac{a_{GSO}}{d}sinb)$$

Antenna Look Angles

- http://www.satlex.de/
- Different positions of Satellite w.r.t. ES [practice]

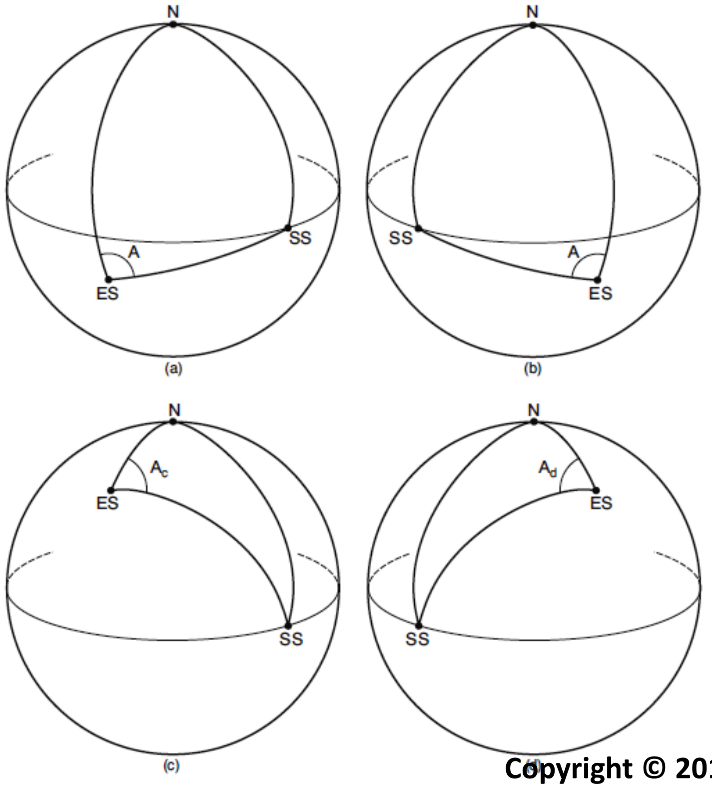


Figure 3.3 Azimuth angles related to angle A (see Table 3.1).

Table of azimuth angle A_z

TABLE 3.1 Azimuth Angles A_z from Fig. 3.3

Fig. 3.3	λ_E	B	A_z degrees
a	<0	<0	A
b	<0	>0	$360° - A$
c	>0	<0	$180° - A$
d	>0	>0	$180° + A$

Antenna Look Angles

- **Example:** A geostationary satellite is located at 90°W. Calculate the azimuth angle for an earth-station antenna at latitude 35°N and longitude 100°W

Antenna Look Angles

- Solution:

Solution The given quantities are

$\phi_{SS} = -90°$ $\phi_E = -100°$ $\lambda_E = 35°$

$$B = \phi_E - \phi_{SS}$$
$$= -10°$$

From Eq. (3.8):

$$b = \arccos(\cos B \ \cos \lambda_E)$$
$$= 36.23°$$

From Eq. (3.9):

$$A = \arcsin\left(\frac{\sin|B|}{\sin b}\right)$$
$$= 17.1°$$

By inspection, $\lambda_E > 0$ and B < 0. Therefore, Fig. 3.3c applies, and

$$A_z = 180° - A$$
$$= \underline{\underline{162.9°}}$$

Antenna Look Angles

- **<u>Example:</u>** Find the range and antenna elevation angle for the situation specified in previous example

Antenna Look Angles

Solution R = 6371 km; a_{GSO} = 42164 km, and from Example 3.1, b = 36.23°.
Equation (3.11) gives:

$$d = \sqrt{6371^2 + 42164^2 - 2 \times 6371 \times 42164 \times \cos 36.23^\circ}$$

$$\cong \underline{\underline{37215\ \text{km}}}$$

Equation (3.11) gives:

$$El = \arccos\left(\frac{42164}{37215}\sin 36.23^\circ\right)$$

$$\cong \underline{\underline{48^\circ}}$$

Antenna Look Angles (Special Case)

- when the earth station is directly under the satellite (on the equator), the elevation is 90°, and the azimuth is irrelevant.
- When the sub-satellite point is east of the equatorial earth station ($B < 0$), the azimuth is 90°, and when west ($B > 0$), the azimuth is 270°.

The Polar Mount Antenna

- A single actuator used to move the antenna in a circular arc to control both azimuth and elevation (known as a *polar mount antenna*)
- The dish is mounted on an axis termed the **polar axis** such that the antenna bore-sight is normal to this axis
- The dish is tilted at an angle δ *(declination/angle of tilt)* relative to the polar mount until the boresight is pointing at a satellite position due south of the earth station such that $\delta = 90° - El_0 - \lambda_E$
- For due south situation: B = 0 → b = λ_E → $El_0 = arccos(\frac{a_{GSO}}{d} sin\lambda_E)$

$$\delta = 90° - arccos(\frac{a_{GSO}}{d} sin\lambda_E) - \lambda_E$$

$$d = \sqrt{R^2 + a_{GSO}^2 - 2Ra_{GSO}cos\lambda_E}$$

The Polar Mount Antenna

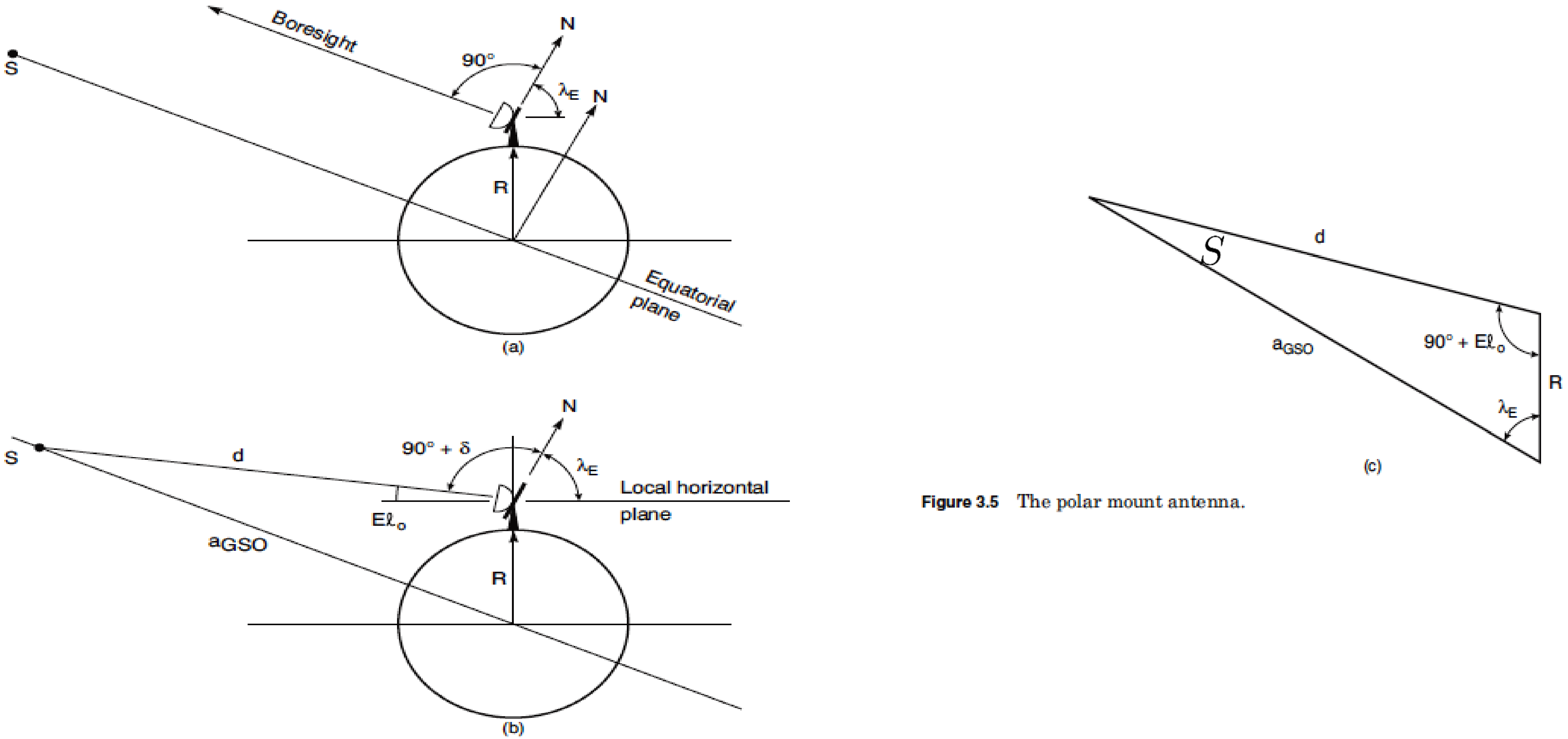


Figure 3.5 The polar mount antenna.

The Polar Mount Antenna

- **<u>Example:</u>** Determine the angle of tilt required for a polar mount used with an earth station at latitude 49° north. Assume a spherical earth of mean radius 6371 km, and ignore earth-station altitude

The Polar Mount Antenna

Solution Given data:

$\lambda_E = 49°$; $a_{GSO} = 42164$ km; $R = 6371$ km; $b = \lambda_E = 49°$.

Equation (3.11) gives:

$$d = \sqrt{6371^2 + 42164^2 - 2 \times 6371 \times 42164 \times \cos 49°}$$

$$\cong 38287 \text{ km}$$

From Eq. (3.12):

$$El = \arccos\left(\frac{42164}{38287} \sin 49°\right)$$

$$\cong 33.8°$$

$$\delta = 90° - 33.8° - 49°$$

$$\cong \underline{7°}$$

Limits of Visibility

- The lowest elevation in theory is zero
- East and west limits on the geostationary arc visible from any given earth station and determined by earth station location and elevation angle
- Considering an earth station at the equator, with the antenna pointing either west or east along the horizontal, limit angle:

$$\theta = arccos(\frac{a_E}{a_{GSO}}) = 81.3°$$

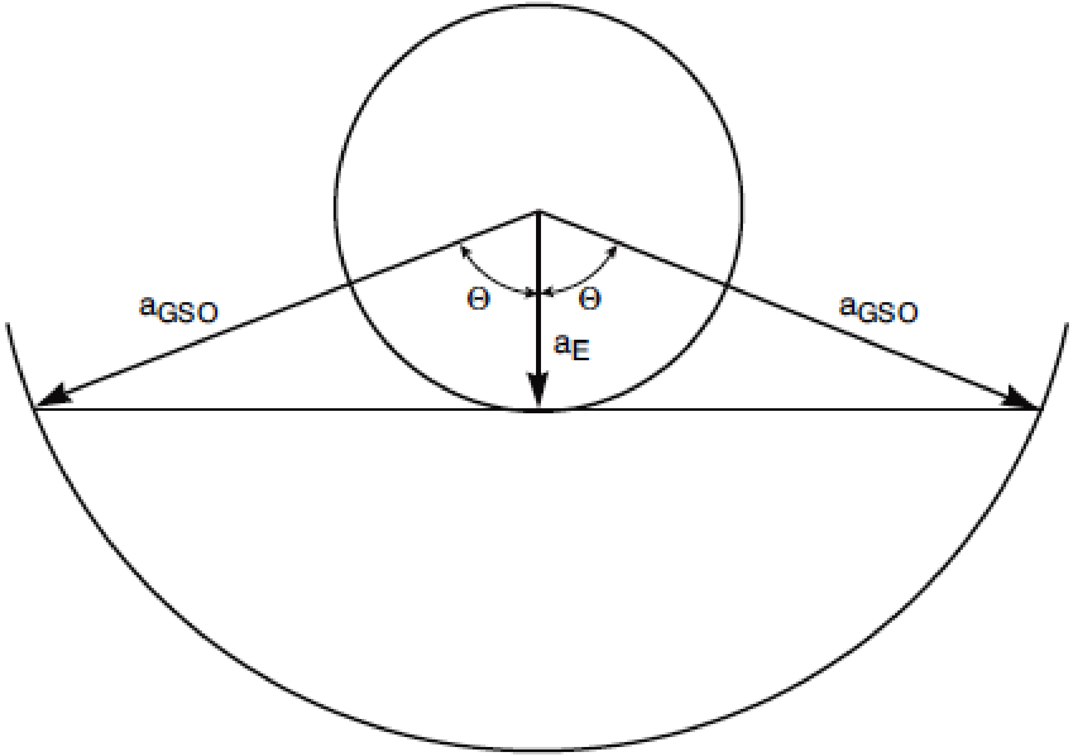
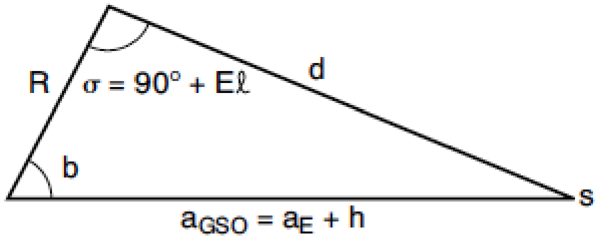


Figure 3.6 Illustrating the limits of visibility.

Limits of Visibility

- to avoid reception of excessive noise from the earth, minimum value of elevation is used $El_{min} = 5°$
- let *S* represent the angle subtended at the satellite when the angle $\sigma_{min} = 90 + El_{min}$ is $S = arcsin(\frac{R}{a_{GSO}} sin\sigma_{min})$
- angle *b* is found from $b = 180 - \sigma_{min} - S$ and B can be directly obtained from b → $B = arccos(\frac{cosb}{cos\lambda_E})$
- Satellite limits of visibility can be obtained by
  - Satellite limit east is: $\phi_E + B$
  - Satellite limit west is: $\phi_E - B$



Limits of Visibility

- **<u>Example:</u>** Determine the limits of visibility for an earth station situated at mean sea level, at latitude 48.42° north, and longitude 89.26 degrees west. Assume a minimum angle of elevation of 5°.

Limits of Visibility

Solution Given data:

$\lambda_E = 48.42°$; $\phi_E = -89.26°$; $El_{min} = 5°$; $a_{GSO} = 42164$ km; $R = 6371$ km

$$\sigma_{min} = 90° + El_{min}$$

Equation (3.17) gives:

$$S = \arcsin\left(\frac{6371}{42164}\sin 95°\right)$$
$$= 8.66°$$

Equation (3.18) gives:

$$b = 180 - 95° - 8.66°$$
$$= 76.34°$$

Equation (3.19) gives:

$$B = \arccos\left(\frac{\cos 76.34°}{\cos 48.42°}\right)$$
$$= 69.15°$$

The satellite limit east of the earth station is at

$$\phi_E + B = \underline{\underline{-20°}} \text{ approx.}$$

and west of the earth station at

$$\phi_E - B = \underline{\underline{-158°}} \text{ approx.}$$

Near Geostationary Orbits

- A number of perturbing forces that cause an orbit to depart from the ideal keplerian orbit:
  - the gravitational fields of the moon and the sun
  - the non-spherical shape of the earth
  - solar radiation pressure and reaction of the satellite itself to motor movement within the satellite
- Station-keeping maneuvers must be carried out to maintain the satellite within set limits of its nominal geostationary position
- Therefore, an exact geostationary orbit therefore is not attainable in practice and orbital parameters vary with time
- Geosynchronous → rotate in synchronism with the rotation of the earth (1.00273896 rev/day)
- Some Geosynchronous may have elliptical orbits with large inclination ! → (not near-geostationary)

Near Geostationary Orbits

- For small inclination (near-geostationary), The longitude of the sub-satellite point (the satellite longitude) is given by:

$$\Phi_{SS} = \omega + \Omega + \nu \; - GST$$

and for the mean position:

$$\Phi_{SSmean} = \omega + \Omega + M \; - GST$$

where

- GST → gives the eastward position of the Greenwich meridian relative to the line of Aries

Two-line elements [practice]

TABLE 2.1 **Details from the NASA Bulletins (see Fig. 2.6 and App. C)**

Line no.	Columns	Description
1	3–7	*Satellite number:* 25338
1	19–20	*Epoch year* (last two digits of the year): 00
1	21–32	*Epoch day* (day and fractional day of the year): 223.79688452 (this is discussed further in Sec. 2.9.2)
1	34–43	*First time derivative of the mean motion* (rev/day^2): 0.00000307
2	9–16	*Inclination* (degrees): 98.6328
2	18–25	*Right ascension of the ascending node* (degrees): 251.5324
2	27–33	*Eccentricity* (leading decimal point assumed): 0011501
2	35–42	*Argument of perigee* (degrees): 113.5534
2	44–51	*Mean anomaly* (degrees): 246.6853
2	53–63	*Mean motion* (rev/day): 14.23304826
2	64–68	*Revolution number at epoch* (rev): 11,663

```
NILESAT 102
1 26470U 00046B   16294.23721428 -.00000078  00000-0  00000+0 0  9995
2 26470   1.1794  84.5135 0005975 142.4779 240.5451  1.00272095 59279
```

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NILESAT 201
1 36830U 10037A   16294.23721428 -.00000078  00000-0  00000+0 0  9997
2 36830   0.0472 163.0511 0004285  40.2890 264.1847  1.00272395 22920
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Earth Eclipse of Satellite

- If the earth's equatorial plane coincided with the plane of the earth's orbit around the sun (the ecliptic plane), geostationary satellites would be eclipsed by the earth once each day
- the equatorial plane is tilted at an angle of 23.4° to the ecliptic plane
- Eclipse occurs at spring and autumn equinox
- Eclipse occurs 23 days before and after equinox (10 min → 72 min per day)

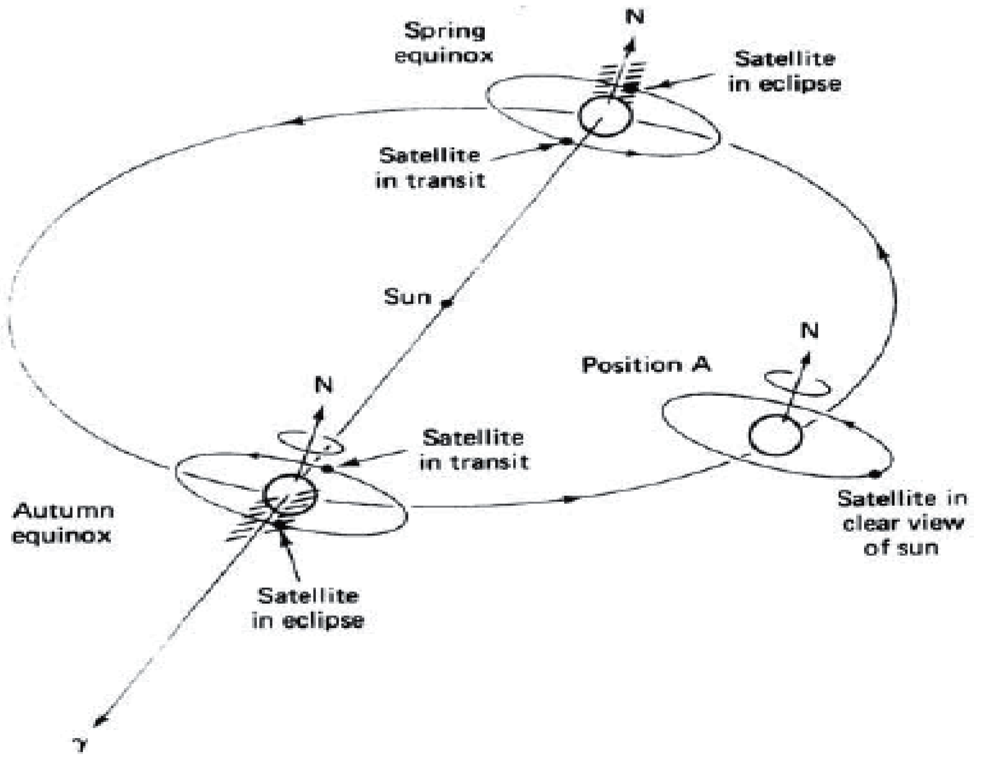

Figure 3.8 Showing satellite eclipse and satellite sun transit around spring and autumn equinoxes.

Sun Transit Outage

- The sun comes within the beam-width of the earth-station antenna
- the sun appears as an extremely noisy source which completely blanks out the signal from the satellite
- lasts for short periods—each day for about 6 days around the equinoxes (typically 10 min)